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FERMILAB-Conf-99/309-E

CDF and D0

W and Z Properties at the Tevatron

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January 2000

Published Proceedings of the *International Europhysics Conference on High Energy Physics*,
Tampere, Finland, July 15-21, 1999

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W and Z Properties at the Tevatron†

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Abstract

We present recent results from CDF and DØ on W and Z production cross sections, the width of the W boson, $\tau - e$ universality in W decays, trilinear gauge boson couplings, and on the observation of $Z \rightarrow b\bar{b}$.

1. Introduction

In this paper we review some recent results on W and Z properties obtained by the CDF and DØ collaborations at the Fermilab Tevatron. The results are based on data sets collected during the 1994-95 run ("Run 1b"), with total integrated luminosities of $\approx 85-90 \text{ pb}^{-1}$ per experiment. CDF (DØ) observed 41,666 (67,078) $W \rightarrow e\nu$ candidate events and 5,152 (5,397) $Z \rightarrow e^+e^-$ candidates.

2. Measurement of the Ratio of $W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$ Cross Sections

New results on the W and Z production cross sections times electronic branching ratios from CDF and DØ are shown in Fig. 1. DØ measure [1] $\sigma_W \cdot B(W \rightarrow e\nu) = 2310 \pm 10 \text{ (stat)} \pm 50 \text{ (syst)} \pm 100 \text{ (lum)} \text{ pb}$ and $\sigma_Z \cdot B(Z \rightarrow e^+e^-) = 221 \pm 3 \text{ (stat)} \pm 4 \text{ (syst)} \pm 10 \text{ (lum)} \text{ pb}$, where "lum" is due to the uncertainty on the integrated luminosity. CDF obtain $\sigma_Z \cdot B(Z \rightarrow e^+e^-) = 249 \pm 5 \text{ (stat} \oplus \text{syst)} \pm 10 \text{ (lum)} \text{ pb}$ and $\sigma_Z \cdot B(Z \rightarrow \mu^+\mu^-) = 237 \pm 9 \text{ (stat} \oplus \text{lum)} \pm 9 \text{ (lum)} \text{ pb}$ [2].

The errors are dominated by the uncertainty in the integrated luminosity of the data samples. The DØ and CDF results must be compared with care, since the experiments use different total $p\bar{p}$ cross sections to determine their integrated luminosities. CDF use their own measurement, while DØ take the average of the CDF, E710 and E811 measurements. As a result there is a scale factor which must be

† Paper presented at the International Europhysics Conference on High Energy Physics, Tampere, Finland, 15-21 July, 1999.

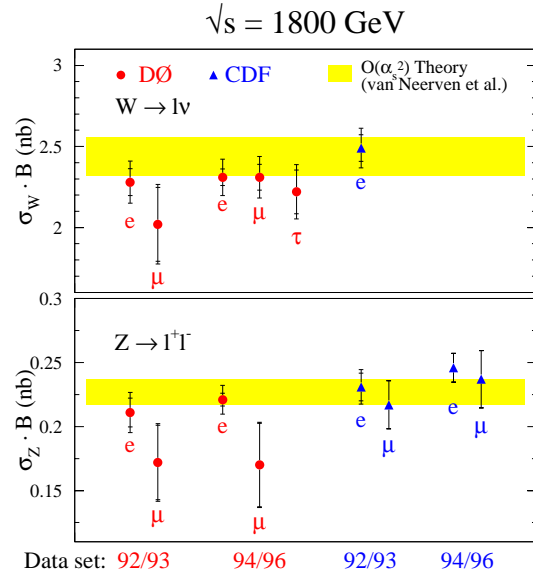


Figure 1. Measurements of the $W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$ cross sections from DØ and CDF.

applied to the measured cross sections: e.g. if using the CDF normalization, the DØ Run 1b cross sections must be multiplied by 1.062. Note that the results in Fig. 1 have *not* been rescaled.

The integrated luminosity uncertainty and many of the other systematic errors cancel in the ratio of cross sections $R = \sigma_W \cdot B(W \rightarrow e\nu) / \sigma_Z \cdot B(Z \rightarrow e^+e^-)$. This allows indirect, precise measurements of the $W \rightarrow e\nu$ branching fraction and the width of the W boson. This follows using

$$\frac{\sigma_W \cdot B(W \rightarrow e\nu)}{\sigma_Z \cdot B(Z \rightarrow e^+e^-)} = \frac{\sigma_W}{\sigma_Z} \frac{1}{B(Z \rightarrow e^+e^-)} \frac{\Gamma(W \rightarrow e\nu)}{\Gamma(W)}$$

together with the theoretical calculation of

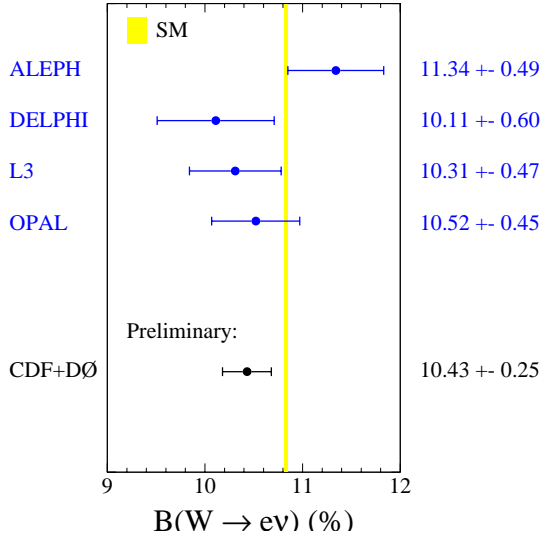


Figure 2. Measurements of $B(W \rightarrow e\nu)$.

σ_W/σ_Z [3], the measured $Z \rightarrow e^+e^-$ branching ratio from LEP [4], and the SM value of $\Gamma(W \rightarrow e\nu)$ [5].

The measured values of R are $R = 10.49 \pm 0.14$ (stat) ± 0.21 (syst) for DØ and $R = 10.38 \pm 0.14$ (stat) ± 0.17 (syst) for CDF, using the combined electron data from Runs 1a and 1b. The main sources of systematic errors are due to uncertainties in backgrounds, efficiencies, and electron energy scale. A 1% error due to NLO electroweak radiative corrections is also included. The two R measurements have been combined, yielding $R = 10.42 \pm 0.18$. Using this combined value of R , the resulting branching fraction is $B(W \rightarrow e\nu) = (10.43 \pm 0.25)\%$ and the width of the W boson is determined to be $\Gamma(W) = 2.171 \pm 0.052$ GeV. The results agree with the SM predictions when the errors are taken into account, as shown in Figs. 2 and 3. A significant source of systematic error (1.5%) arises from the theoretical uncertainty on σ_W/σ_Z due to the choice of renormalization scheme and electroweak radiative corrections. Note that at present the errors due to theoretical uncertainties on $B(W \rightarrow e\nu)$ and $\Gamma(W)$ are larger than the statistical uncertainty.

A direct measurement of the W boson width is possible using a fit to transverse mass (M_T) spectrum in W events. The W width directly affects the shape of the distribution, most prominently at high values of M_T , where the Breit-Wigner line shape dominates over detector resolution effects. CDF have new preliminary results for Run 1b $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ events, using a binned likelihood fit in the region $M_T > 100$ GeV/ c^2 . The

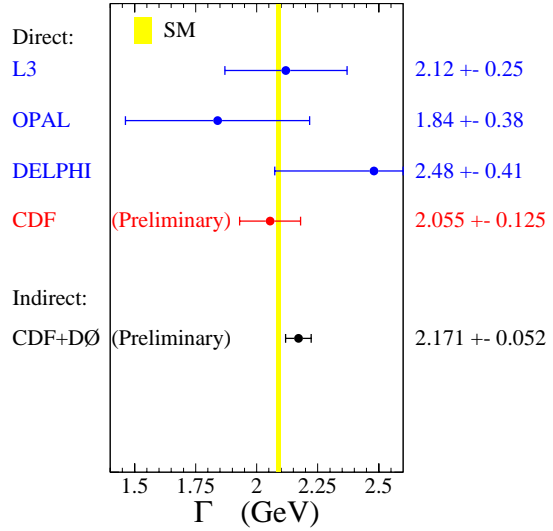


Figure 3. Direct and indirect measurements of the W boson width.

W events are modeled using a similar simulation to that used in the W mass analyses [6]. This method is less model-dependent than the indirect measurement discussed above, but with the current data sets it is statistically limited. The transverse mass fits are shown in Figs. 4 and 5. The results are $\Gamma(W) = 2.17 \pm 0.125$ (stat) ± 0.105 (syst) GeV from the electron data and $\Gamma(W) = 1.78 \pm 0.195$ (stat) ± 0.135 (syst) GeV from the muon data. These results are combined with the Run 1a electron measurement, yielding $\Gamma(W) = 2.055 \pm 0.100$ (stat) ± 0.075 (syst) GeV. This result is consistent with the SM prediction, as shown in Fig. 3.

3. $\tau - e$ universality in W decays

DØ have updated their preliminary measurement of the W cross section times $W \rightarrow \tau\nu$ branching ratio using Run 1b data and the new luminosity normalization, and obtain $\sigma_W \cdot B(W \rightarrow \tau\nu) = 2220 \pm 90$ (stat) ± 100 (syst) ± 100 (lum) pb. The ratio of this quantity to the corresponding electron-channel quantity measures the ratio of the electroweak charged current couplings, g_τ^W/g_e^W . DØ measure $g_\tau^W/g_e^W = 0.98 \pm 0.03$, to be compared with the earlier CDF result of $g_\tau^W/g_e^W = 0.97 \pm 0.07$ using Run 1a data, and the preliminary CDF result $g_\tau^W/g_e^W = 1.01 \pm 0.19$ which uses Run 1b data, but is obtained from an analysis based on the difference in electron impact parameter distributions in $W \rightarrow \tau\nu \rightarrow e\nu\nu\nu$ and $W \rightarrow e\nu$ events. These results are shown in Fig. 6.

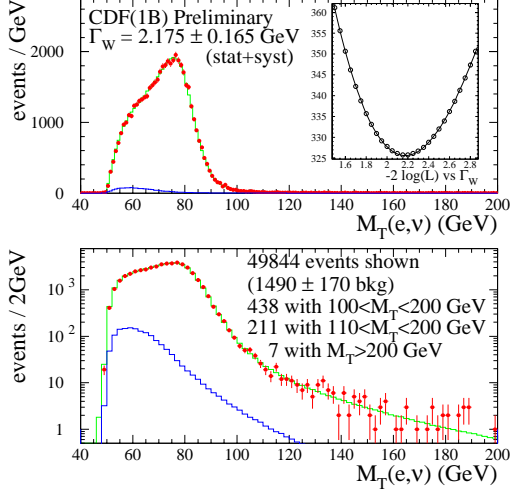


Figure 4. CDF direct measurement of the W boson width using a fit to the $e\nu$ transverse mass.

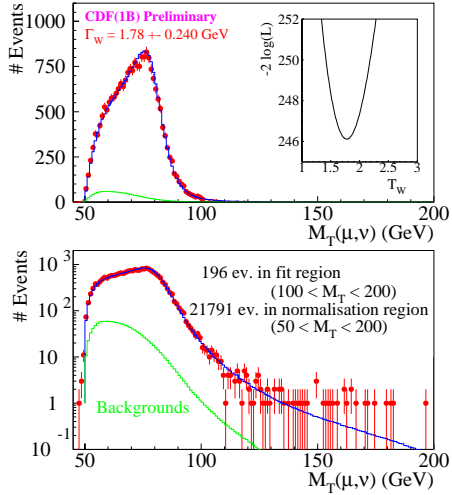


Figure 5. CDF direct measurement of the W width using a fit to the $\mu\nu$ transverse mass.

4. Updated DØ results on trilinear gauge boson couplings

DØ have recently published limits on the trilinear gauge boson couplings from $p\bar{p} \rightarrow WW/WZ \rightarrow \mu\nu jj$ events [7]. They use a likelihood fit to the $p_T(\mu\nu)$ spectrum, which is sensitive to non-SM couplings. Anomalous couplings would result in an enhancement of events at high $p_T(\mu\nu)$. No such enhancement is seen and DØ obtain 95% confidence level limits, assuming equal $WW\gamma$ and WWZ couplings (i.e. $\lambda_\gamma = \lambda_Z$ and $\Delta\kappa_\gamma = \Delta\kappa_Z$) using a dipole form factor with form factor scale

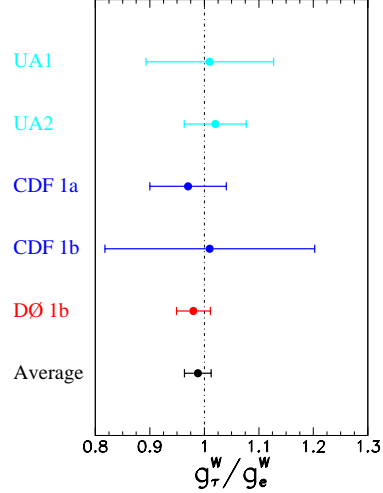


Figure 6. Measurements of g_τ^W/g_e^W .

$\Lambda_{FF} = 2$ TeV: $-0.52 < \lambda < 0.54$ and $-0.62 < \Delta\kappa < 0.88$.

DØ have also searched for WZ events in the $e\nu ee$ and $\mu\nu ee$ channels [7]. One event passes the selection criteria, an $e\nu ee$ candidate, shown in Fig. 7. For both channels combined, the SM prediction is 0.245 ± 0.0154 events, with an estimated background of 0.50 ± 0.15 events. In the absence of an excess of events, which would be an indication of non-SM WWZ couplings, DØ set limits on anomalous couplings. This analysis is most sensitive to the couplings λ and Δg_1^Z , with resulting limits $|\lambda| < 1.42$ and $|\Delta g_1^Z| < 1.63$ at the 95% CL, using a form factor scale of 1 TeV. Because WZ production is sensitive only to the WWZ coupling, these results are independent of any assumptions about the $WW\gamma$ coupling.

The new results on the trilinear gauge boson couplings have been combined with previous results from DØ to yield new global limits from DØ utilizing all diboson production analyses. Figure 8 shows the results for the couplings $\Delta\kappa$ and λ . The DØ results use a form factor scale of 2 TeV, and therefore, the LEP errors should be scaled by a factor of $(1 + s/\Lambda_{FF})^2$ when comparing with DØ. Here, s is the LEP c.m. energy. This is *not* done in Fig. 8, since the effect only amounts to a few percent increase. As can be seen, the DØ results are comparable to those from the LEP experiments, and because of the different production mechanisms and effects of anomalous couplings, the results are complementary.

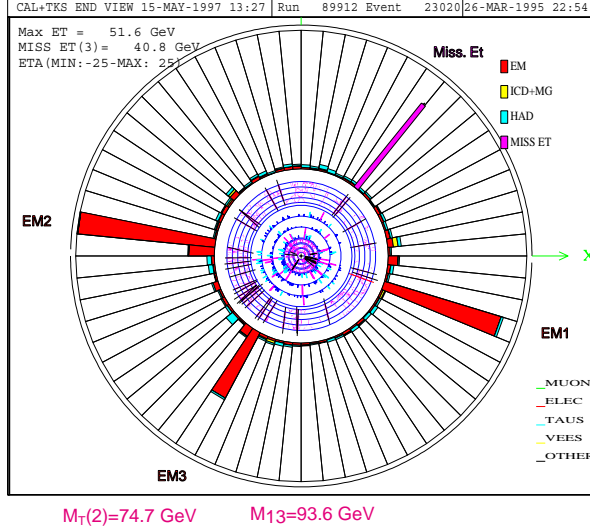


Figure 7. End view of the DØ calorimeter and tracking systems showing a candidate $WZ \rightarrow e\nu ee$ decay.

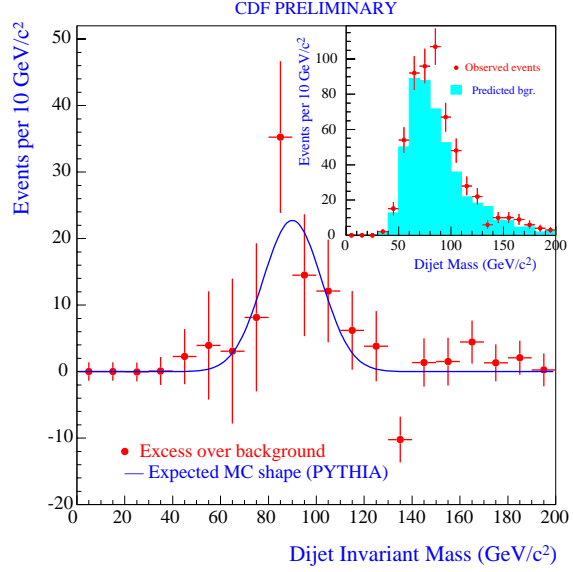


Figure 9. CDF $Z \rightarrow b\bar{b}$ invariant mass plot. The figure shows the dijet invariant mass for events containing a central muon and two SVX-tagged jets.

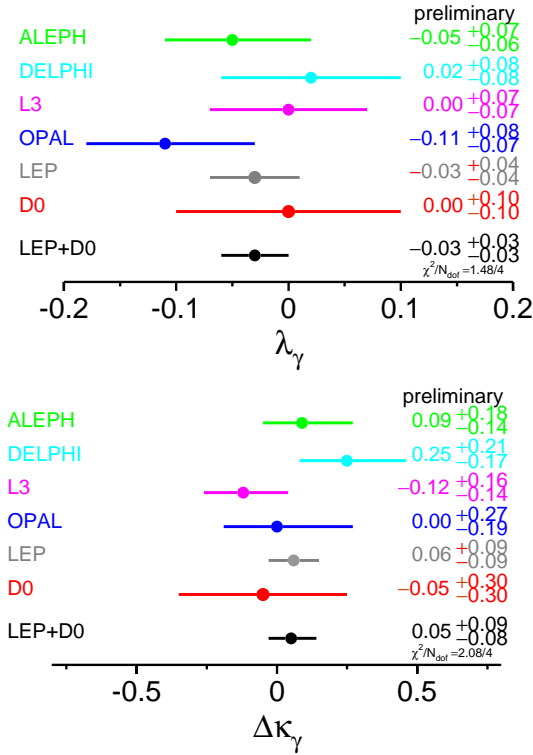


Figure 8. Measurements of the trilinear gauge boson coupling parameters λ and $\Delta\kappa$ from DØ and LEP.

5. CDF observation of $Z \rightarrow b\bar{b}$

The $Z \rightarrow b\bar{b}$ decay channel, copious at LEP and SLC, is challenging to observe at the Tevatron due to the large QCD dijet background. However, it is an important benchmark signal for future physics at the Tevatron – it can be used to improve the jet resolution in Higgs searches involving the $H \rightarrow b\bar{b}$ decay, and it will be an important calibration tool for the top quark mass measurement.

In the CDF analysis, semi-leptonic decays of the b -quark are utilized by selecting events from a sample collected with a central muon trigger. Offline, a good muon candidate with $p_T > 7.5$ GeV is required, together with two jets containing charged tracks forming a well-identified, displaced secondary vertex in the Silicon Vertex Detector. Topological cuts are applied to reject QCD background, based on the amount and topology of the radiation surrounding the two leading jets. Figure 9 shows the background-subtracted dijet invariant mass distribution. The peak and width of the distribution are as expected from Monte Carlo $Z \rightarrow b\bar{b}$ signal. Accounting for the systematic uncertainty on the background prediction (4%), the significance of the excess over background is 3.2 standard deviations.

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